ON THE MEASUREMENT OF ULTRASONIC ENERGY DENSITY IN ABNORMAL LIQUIDS IN RELATION TO THEIR STRUCTURAL CHARACTERISTICS BY SPHERICAL RADIOMETER METHOD

T. C. BHADRA

BOSE INSTITUTE, CALCUTTA-9, INDIA

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ABSTRACT. Ultrasonic energy densities which represent the amount of energy abstracted from the source by the molecular system confined in unit volume of highly abnormal liquids-carbon disulphide, carbon tetrachloride, benzene and less abnormal liquids—water, methyl alcohol, ethyl alcohol, η-propyl alcohol and η-butyl alcohol, have been measured by Spherical Radio-Meter method in absolute units to demonstrate the structural dependence.

Observed results show that it is dependent on the ratio of the number of CH groups to OH groups in the case of water and alcohol series.

In highly abnormal liquids, energy density varies inversely as velocity and directly as density and acoustic impedence, where as in alcohol series energy densities varies directly as velocity, density and acoustic impedence.

Such measurement on water indicates anomalous behaviour.

INTRODUCTION

This paper presents the results of the measurements of ultrasonic energy densities in two groups of abnormal liquids classified by Pinkerton (1949) as $A1$ and $A2$. He made this classification according to ultrasonic absorption. Highly abnormal liquids in $A1$ include carbon disulphide, benzene and carbon tetrachloride and the less abnormal liquids in $A2$ include water, methyl alcohol, ethyl alcohol, n-propyl alcohol, and n-butyl alcohol. Energy density represents the amount of energy abstracted from the source by the molecular system confined in unit volume. It is dependent on the structure of the molecules. Structural relaxation time determines the amount of energy that can be abstracted. It is also dependent on the ratio of the number of CH groups to OH groups present in a molecule. The OH group comprises the dipole. The dipole motion in the case of alcohol involves the rotation of the OH group about the C–C bond without large rearrangements of the surrounding lattice structure. In the case of water the whole molecule is involved in the rotational motion. It is expected that this state of affairs should be reflected on the measured values of energy densities. Liquids belonging to abnormal ($A1$) group are non-polar and anomalous behaviour of the absorption of ultrasonic energy are observed in these cases.

Ultrasonic energy densities in liquid media were measured by Spherical Radio-Meter method as developed by Bhadra (1955). The strength of the primary source of ultrasonic energy was kept constant during all such measurements and the experiments were carried out under almost identical conditions.

THEORETICAL CONSIDERATION

King's (1934) original formula to calculate the mean radiation pressure of plane progressive waves in a medium on a sphere is given as follows

$$\bar{P} = 2\pi\rho_0 \frac{|A|^2}{\alpha^2}\left[\frac{1}{H_0^2 H_1^2} + \frac{2}{H_1^2 H_2^2}\cdot\frac{\{\alpha^2 - 3(1-\rho_0/\rho_1)\}^2}{\alpha^3} + \sum_{n=2}^{\infty}\frac{(n+q)}{H_n^2 H_{n+1}^2}\cdot\frac{\alpha^2 - n(n+2)\}^2}{\alpha^{4n+4}}\right] \quad (1)$$

where $\bar{P}$ is the total force acting on the sphere of radius r, ρ_0 and ρ_1 the densities of the liquid and the sphere respectively, A the coefficient associated with the velocity potential of the incident radiation field, and $\alpha = Kr$,

$$K = w/c = 2\pi f/c = 2\pi/\lambda.$$

λ being the acoustic wave-length. The above expression may be written in the form

$$\bar{P} = \rho_0 |A|^2 F \quad .. \quad (2)$$

in which F is a function of α and ρ_0/ρ_1, while the mean total energy density of the waves is

$$\bar{E} = \tfrac{1}{2}\rho_0 K^2 |A|^2 \quad .. \quad (3)$$

Putting $Y = 2F/\pi\alpha^2$ and combining (2) and (3), the total mean force may be expressed as

$$\bar{P} = Y\bar{E}(\pi\gamma^2) \quad .. \quad (4)$$

It has been shown by Fox (1940) that Y approaches unity as α increases, so that equation (4) may be written in the form

$$\bar{P} = \pi\gamma^2\bar{E} \quad \text{or} \quad \bar{E} = \bar{P}/\pi\gamma^2 \quad (5)$$

with which the energy density can be obtained with fair accuracy.

EXPERIMENTS AND RESULTS

The general principle of the apparatus used follows that first developed by Bhadra (1953, 1955). Further modifications have been made here to meet the experimental exigencies.

An X-cut quartz crystal blank 6·00 sq.cms. in effective area and 0·287 cm. in thickness was excited to vibrate at the fundamental resonant frequency of 1 Mc/s. Ultrasonic energy was generated in transformer oil. Experimental

arrangements were made to direct the ultrasonic energy flow in the vertical direction. Liquids under investigation were taken in a glass vessel the bottom of which was closed by a thin sheet of cellophane. The cellophane sheet was used to transmit the ultrasonic energy from the first medium, the transformer oil to the second medium, the experimental liquids, practically without any diminuation. Cellophane sheet also served as a screen for the streaming of liquids. Ultrasonic energy detector, a steel ball suspended from the bottom of a scale pan by means

Table 1

Liquid Group	Density of liquid gm/c.c.	U.S. Velocity in liquid m/s.	Acoustic impedence of liquid.	Average energy density ergs/cm^3.	Difference
Abnormal (*A*1)					
Benzene (C_6H_6)	0.872	1310	1144.3	9.31	
Carbondisulphide (SC_2)	1.258	1149	1445.4	16.35	
Carbon tetrachloride (CCl_4)	1.596	928.5	1482.1	21.75	
Abnormal (*A*2)					
Water (H–OH)	0.9972	1494	1489.8	6.21	5.79
Methyl alcohol	0.792	1130	895.0	12.00	
					2.07
Ethyl alcohol	0.801	1207	965.8	14.07	
					2.49
n-propyl alcohol	0.806	1234	989.4	16.56	
					2.06
n-butyl alcohol	0.808	1315	1062.5	18.62	

of a fine thread from one of the arms of a sensitive chemical balance was located at a fixed distance from the face of the transducer in all experiments. The pressure developed on the steel sphere due to the passage of ultrasonic energy was measured in absolute unit.

Maximum probable error in each measurement of pressure is ± 10 mgm wt. This corresponds to the minimum detectable pressure change in the entire range of measurements. When this figure is expressed in percentage error, it will vary in range 1·7 to 2·0%, depending upon the intensity of ultrasonic energy used for each set of runs.

Results obtained from such measurements of ultrasonic energy density are summarised in table 1.

DISCUSSIONS

The table 1 shows clearly that the magnitudes of energy densities in liquids of groups (*A*1 and (*A*2), with the exception of water, increase with the acoustic impedences. Further, the difference column in the case of liquids (*A*2) indicates the existence of some relation of energy density with the structure of liquid. It is evident from these values that except in case of water there is regularity in the increase in the values of energy density in alcohol series; some irregularity is observed when one CH_2 group is added to water molecule to get methyl alcohol molecule. Non-liniarity of water molecule structure and clustering or more molecules together in water might be responsible for such a large deviation in the values of energy density from the regularity that is followed in alcohol series. In the case of the alcoholic series starting with methyl alcohol, it is evident that the magnitude of energy density increases approximately by equal amounts, with the increase of the linear length of the molecule due to the addition of a CH_2 group to a molecule. In the case of the liquids belonging to abnormal (*A*1) group, no such chain forming sequences are present. Molecular structures of each substance are distinct by themselves. So here no inference indicating the relation of energy density and linear dimension of molecules is possible. Further work to search for such a relation is in progress.

It is also evident from the table 1 that in alll iquids, excepting water, energy densities increase with densities but the energy densities increase with the decrease of ultrasonic velocities in liquids belonging to abnormal (*A*1) and increase with the increase of velocites in the case of liquids belonging to abnormal (*A*2). Water having the highest density and the velocity, shows the least energy density. Intriguing character of water is revealed here. Ultrasonic energy absorption in water can be explained by assuming two state model proposed by Hall (1948). But in the case of alcohol, the two state model is not completely adequate to describe the experimental data. This is evident from the presence of a distribution of relaxation times measured in the dispersion region. It is implicit in the

two state theory that a single relaxation time exists. As such there is the possibility that more than two states exists in alcoholes.

These data are not sufficient enough to establish a relation between the energy density and structure of the liquids. To achieve the goal measurements of energy density are being continued on liquids from groups (*A*1) and (*A*2) as function of frequency.

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